HOW SIGNAL CURRENTS ARE KEPT IN CORRECT PATHS

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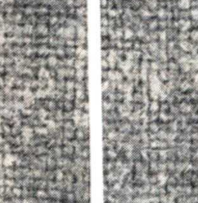

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STUDY SCHEDULE No. 20

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions specified for that step. Study each other step in this same way.

☐ 1. Introduction; By-pass Condensers .... Pages 1-6

How undesired signal currents get into a circuit; Methods of Keeping Signal Currents in Correct Paths; action of circuit having no by-pass condensers; Tracing Signal Currents; Cathode Circuit; Cathode C Bias Resistor By-Pass Condenser; Screen Grid Circuit; Screen Grid By-Pass Condenser; Plate Circuit; Plate Supply By-Pass Condenser; Practical Amplifier Circuit; By-Pass Condenser Rule. Answer Lesson Questions 1, 2, 3 and 4.

☐ 2. Simple Signal Current Filters; D.C. Blocking Condensers .... Pages 6-10

Simple Condenser Filter; Coil-Condenser and Resistor-Condenser Filters; Dual Condenser Filters; Pi or Low-Pass Filters; Practical Examples of Signal Current Filter Circuits; coupling problems; use of D.C. blocking condensers for coupling purposes. Answer Lesson Question 5.

☐ 3. Importance of Proper Connections .... Pages 11-15

Regeneration and degeneration effects due to stray coupling between leads, stray currents in the metal chassis or common coupling through the gang tuning condenser; Proper Connections in a Single R.F. Stage; Effects of Stray Chassis Currents; Stray currents in Ganged Variable Condensers. Answer Lesson Questions 6 and 7.

☐ 4. Shields for Electric Fields; Electromagnetic Shields; Positioning of Parts for Minimum Interference; Twisting of Power Supply Leads .... Pages 15-23

Electrostatic and electromagnetic induction; How Electric Fields Affect Grid Circuits; Sources of Electric Fields; Shielding of Coils; Practical Data on Electric Shields; electromagnetic shielding problems; Shields for Low-Frequency Magnetic Fields; Shields for High-Frequency Magnetic Fields; how positioning of parts can minimize interfering effects; Positioning of Wires; Positioning of Coils; magnetic coupling between parallel and twisted wires. Answer Lesson Questions 8 and 9.

☐ 5. Center-Tapped Filament Connections; Analysis of Signal Current Circuits in a Typical Radio Receiver ... Pages 23-29

Interference problems in filament-type tubes; A.C. hum interference; use of center-tapped filament resistor to eliminate hum; schematic circuit diagram of typical 5-tube superheterodyne receiver; tracing signal current paths; locating and identifying extra parts used to keep signal currents in correct paths; analysis of chassis layout to see how effects of stray electric and magnetic fields are minimized by proper placement of parts. Answer Lesson Question 10.

☐ 6. Mail Your Answers for this Lesson to N.R.I. for Grading.

☐ 7. Start Studying the Next Lesson.

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How Signal Currents Are Kept in Correct Paths

Introduction

UNDESIRED signal currents can enter a circuit in three different ways: *1*, through a *conductive path* such as a wire or a metal chassis; *2*, by *electrostatic induction*, where the electric field set up by one circuit repels and attracts electrons in another circuit; *3*, by *electromagnetic induction*, where the magnetic field set up by one circuit induces interfering currents in another circuit.

Undesired signal currents are kept out of circuits and desired signal currents are kept in their correct paths by many different methods; although these are generally applied to radio apparatus by design engineers, a knowledge of how each method works is needed by the radio operator or serviceman who is called upon to locate and remedy a defect in some circuit.

The most important of these methods for controlling signal current paths are listed below; many of these have been covered in previous lessons, but this entire subject is of such great practical importance that a more detailed study is entirely justified.

By-Pass Condensers

The importance of by-pass condensers can best be understood by considering the behavior of an amplifier stage which has no by-pass condensers. Such a stage is shown in Fig. *1A*, where the input device R_S (across which the input signal voltage e_S appears) and the plate load R_L are shown as resistors. Although tuned circuits and transformers could be used at these locations in practical circuits, under ideal conditions they have the effect of resistors and will therefore be considered as such here.

When the input signal voltage e_S in Fig. *1A* is zero, the control grid of the tube is at a fixed potential, the value of

METHODS OF KEEPING SIGNAL CURRENTS IN CORRECT PATHS

1. **Using by-pass condensers.**
2. **Using R.F., I.F. and A.F. signal current filters made up of resistors, coils and condensers.**
3. **Using D.C. blocking condensers.**
4. **Making proper circuit connections, in order to prevent stray coupling between leads and parts and to eliminate stray currents.**
5. **Shielding signal circuit parts against the effects of stray electric fields.**
6. **Shielding circuit parts against the effects of stray magnetic fields.**
7. **Positioning of power pack and signal circuit parts in such a way that magnetic and electric fields cannot cause interference.**
8. **Twisting filament leads and power supply leads which carry A.C., or running such leads parallel to each other and close together.**
9. **Using center-tapped filament connections for grid and plate return leads.**
10. **Using neutralizing circuits to counteract the effects of R.F. and I.F. feed-back currents. (This last method is covered elsewhere in the Course and will not be repeated here.)**

which determines how much D.C. plate current and D.C. screen grid current will flow. The directions of electron flow in various parts of the amplifier under this condition are indicated by arrows directly on the circuit lines in Fig. *1A;* you can easily verify these directions by remembering that electrons leave the minus terminal of the B battery (the only D.C. source in the circuit) and travel from cathode to plate or from cathode to screen grid in the tube. The D.C. screen grid and plate currents both flow through resistor R_C, developing across it a D.C. voltage drop which serves as the normal C bias for the tube and which therefore serves to determine the values of these D.C. electrode currents.

When an input A.C. signal voltage e_S is applied across R_S, it makes the control grid alternately more and less negative than the normal negative C bias value; when this input signal swings the control grid less negative (more positive), D.C. plate and screen grid currents both increase a certain amount, and when the input signal swings the control grid more negative, the D.C. plate and screen grid currents decrease. The application of an input signal on the control grid is thus causing the D.C. plate and screen grid currents to vary continually above and below their normal no-signal values, and we actually have pulsating D.C. currents in these two circuits.

We know definitely that the vacuum tube, when acted upon by the input signal, causes these variations in the electron current which is sent through the screen grid and plate circuits by the B battery; it is quite permissible, therefore, to think of the vacuum tube as simply a variable resistance acting in the plate circuit (and also in the screen grid circuit) and thereby producing these variations or pulsations in plate and screen grid currents. If we say that this tube resistance is varying at exactly the same rate and in the same manner as the grid input A.C. signal, we can neglect the grid circuit entirely and concentrate our attention upon the plate and screen grid circuits, through which the B battery is forcing the pulsating currents.

In an amplifier circuit we are primarily interested in the pulsations or variations in plate current, for these develop across load resistor R_L the desired amplified signal voltage. We could consider only this A.C. or signal component of the plate current, and think of it as acting in a circuit made up of the B battery and a varying cathode-to-plate resistance in the tube, but experience has shown that an analysis or study of the circuit under this condition becomes quite complicated.

There is a much easier way of dealing with A.C. or signal currents in the plate and screen grid circuits of an amplifier—a method which is almost universally used by engineers because of its simplicity. This method involves neglecting the D.C. electrode currents entirely, and considering the *vacuum tube* as our source for A.C. or signal currents. (The battery is neglected as a voltage source and considered simply as a resistor equal to the internal battery resistance R_B in Fig. *1A*). In other words, we replace the entire grid circuit and the cathode-plate path of the tube with an A.C. generator having a given internal resistance (the A.C. plate resistance) when we deal with the plate circuit, and we likewise consider an A.C. generator in place of the cathode-screen grid path of the tube when dealing with the screen grid circuit. (You will recall that this is exactly what was done in the equivalent tube circuits studied in a previous lesson.)

The tracing of signal currents (A.C. components of electrode currents) in Fig. *1A* is quite simple now that we can consider the tube as the A.C. source. A.C. plate current i_p flows through the cathode-plate path of the tube (its source) to the plate, flows through load R_L, flows to point *2* (the chassis) either through the B battery or through voltage divider R_1-R_2, and then returns to the cathode through R_C; arrows labeled i_p indicate these paths. A.C. screen grid current flows through the cathode-screen grid path of the tube (its source) to the screen grid electrode, flows to point *2* (the chassis) either through R_1, or through R_2 and the B battery, and then returns to the cathode through R_C; arrows labeled i_{sg} in Fig. *1A* indicate these paths.

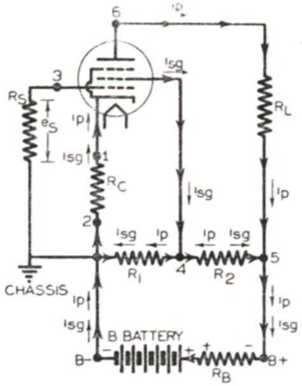

Fig. 1A. Simplified pentode amplifier circuit, with all by-pass condensers omitted. Arrows on circuit lines indicate D.C. electron flow, while other arrows indicate paths taken by signal currents

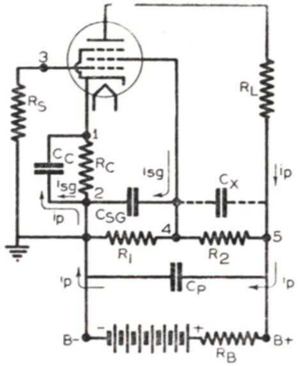

Fig. 1B. Three by-pass condensers inserted in the amplifier circuit of Fig. *1A*, as shown above, effectively serve to keep signal currents in their proper paths, eliminating interfering effects.

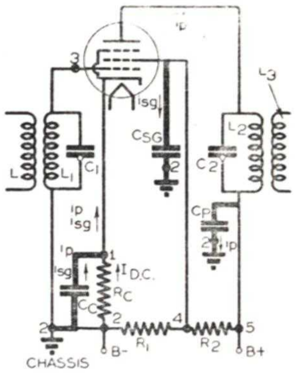

Fig. 1C. Pentode R.F. amplifier circuit of Fig. *1A* with suitable by-pass condensers to provide low-reactance paths for signal currents. Actual tuned input and output circuits are shown instead of resistors.

Cathode Circuit. Both the plate and screen grid signal currents flow through C bias resistor R_C, producing A.C. voltage drops across it. Since the control grid voltage is developed across R_C, these A.C. voltage drops act on the control grid along with the input signal voltage e_S, and *degeneration* occurs. What actually happens is this: When the input signal e_S is increasing in a positive direction, making point *3* more positive with respect to point *2*, the plate and screen grid signal currents through R_C will be increasing. Since electron flow for these currents is from point *2* to point *1*, point *2* will be made increasingly more negative with respect to point *1*. We thus have acting on the control grid of the tube (applied to the grid and cathode terminals of the tube) the positively increasing input signal voltage and the negatively increasing A.C. voltage developed across the C bias resistor. These A.C. voltages oppose each other (are out of phase with each other) and hence the net A.C. voltage on the grid is reduced, with *degeneration* or reduction of signal current as a result.

Cathode C Bias Resistor By-Pass Condenser. The method commonly used to keep signal currents out of the

C bias resistor and thus prevent degeneration from occuring in the cathode circuit involves placing a by-pass condenser across the C bias resistor, making the reactance of this condenser low enough at the lowest signal frequencies so that the signal currents will take the path through the condenser rather than through the C bias resistor. This is done in Fig. *1B*, where C_C is the cathode by-pass condenser which is connected across C bias resistor R_C. The A.C. voltage drop across this condenser will be negligibly low because the by-pass condenser has practically no reactance at signal current frequencies, and hence the only A.C. voltage acting on the grid will be the input signal voltage. The D.C. components of screen grid and plate current will continue to flow through R_C, producing across it the desired C bias voltage.

Screen Grid Circuit. Now let us see what undesirable effects are produced by A.C. screen grid current in the amplifier circuit of Fig. *1A*. We note that the screen grid gets its D.C. voltage from a tap at point *4* on the voltage divider network made up of R_1 and R_2. The voltage of this point with respect to point *2* (B-) depends upon the ohmic values of R_1 and R_2 and upon the current which flows through each resistor to produce across it a voltage drop. From Kirchhoff's voltage law we know that the sum of the voltage drops across R_1 and R_2 must equal the B battery voltage; stated in another way, the screen grid supply voltage (the drop across R_1) will be equal to the B battery voltage minus the voltage drop across R_2.

Consider the A.C. screen grid current path through R_2. When a positively increasing control grid voltage causes screen grid current through R_2 to increase, the voltage drop across R_2 will increase and consequently the voltage drop across R_1 (the screen grid voltage) will *decrease*. A decreasing screen grid voltage means a decreasing A.C. plate current, and consequently we have *degeneration*, a reduction in signal output, as an undesirable effect of A.C. screen grid current in this circuit.

Screen Grid By-Pass Condenser. A.C. screen grid current could be kept out of R_2 by placing across it a by-pass condenser (C_X in Fig. *1B*) which provided a low-reactance path around this resistor for this current, but a more practical solution is one which places a by-pass condenser between the screen grid lead (point *4*) and the cathode lead (point *2*); condenser C_{SG} in Fig. *1B* is connected in this way. Now A.C. screen grid currents have a direct low-reactance path from point *4* to point *2* and then through C_C to the cathode, and consequently there will be no degeneration. This practical solution keeps A.C. grid current i_{sg} out of the source as well as out of R_2.

Plate Circuit. We still have the effects of *A.C. plate current* to consider in the circuit in Fig. *1A*. This current (i_p) flows through the B battery along with the A.C. screen grid current i_{sg}. Any voltage source has a certain amount of internal resistance; this resistance can be considered as acting in series with the source in Fig. *1A*, and resistor R_B therefore represents the battery resistance through which these signal currents must flow.

We have seen how screen grid signal current can be made to take a proper path, but we still have plate signal current flowing through this battery resistance and producing a voltage drop across it. By considering the directions of electron flow (indicated by arrows in Fig. *1A* for the case where the grid signal is positively increasing) you can see that this voltage drop causes the potential of point *5* (the supply voltage) to decrease with respect to point *2* when the grid input voltage increases. The flow of signal current through the battery thus reduces the plate supply voltage and the plate current, and again we have *degeneration*. Furthermore, any A.C. plate currents which take the R_1-R_2 path from point *5* to point *2* instead of going through the battery may also cause undesirable effects.

Radio apparatus today generally contains a number of vacuum tube stages all connected to a common supply source. Any other tubes connected to the battery in Fig. *1A* would consequently be affected by the signal voltage drops across the battery resistance and would undergo either regeneration or degeneration, depending upon whether the undesired voltage drops aided or opposed changes in plate current in a particular stage. Clearly it is undesirable to allow signal currents to flow through the plate supply or the voltage divider.

Plate Supply By-Pass Condenser. A by-pass condenser connected directly across the plate supply, like C_P in Fig. *1B*, will offer a low-reactance path for signal currents to point *2* (the chassis), thereby keeping them out of the higher-resistance paths through the plate supply and voltage divider and eliminating undesirable degeneration or regeneration effects.

The plate by-pass condenser also lowers the impedance of the A.C. plate current path, allowing more A.C. plate current to flow through load resistor R_L and thereby developing across it a higher output signal voltage. No useful A.C. plate voltage is wasted now in the internal battery resistance R_B.

Practical Amplifier Circuit. One example of a practical circuit which requires by-pass condensers is that shown in Fig. *1C*, representing a pentode I.F. amplifier stage of a superheterodyne receiver. The connections to the three by-pass condensers are shown by heavy lines to make them easy for you to locate. In this circuit, bypass condensers C_P and C_{SG} are both connected to point *2* on the chassis, to which R_C is also connected, and low-reactance by pass condenser C_C is relied upon to provide a path from the chassis to the cathode for the signal currents. Oftentimes, however, these by-pass condensers are connected directly from the plate and screen grid circuits to the *cathode*. Design engineers choose whichever method gives the shortest leads, for long leads result in electric and magnetic fields which produce undesirable coupling between circuits.

BY-PASS CONDENSER RULE

In a vacuum tube circuit, all signal currents are by-passed through condensers to the cathode after they leave the electrodes or circuit parts through which they must flow to give the desired circuit action. **Signal currents will take the path through a by-pass condenser in preference to other possible paths between two points in a receiver circuit because** ***the by-pass condenser has practically no reactance at signal current frequencies;*** **in fact, a by-pass condenser is the equivalent of a direct wire connection for these currents.**

Occasionally a design engineer omits a by-pass condenser specifically to secure regeneration or degeneration, or uses a single C bias resistor and by-pass condenser for two or more tubes.

A few typical examples will fix in your mind the general rule for applying by-pass condensers. A simple triode vacuum tube circuit like that shown in Fig. *2A* requires two by-pass condensers. A simple tetrode circuit like that in Fig. *2B* requires three by-pass condensers. A circuit containing a pentode tube in which the suppressor grid is tied directly to the cathode will likewise need three by-pass condensers. In a pentode tube circuit where the suppressor grid is not at cathode potential, as in Fig. *2C*, four by-pass condensers are needed to keep signal currents in their correct paths. Occasionally a vacuum tube is used in a circuit where the control grid is at cathode potential (zero C bias); in cases like this the cathode resistor and the cathode by-pass condenser in the circuits of Fig. *2* would be omitted and the cathode would be grounded.

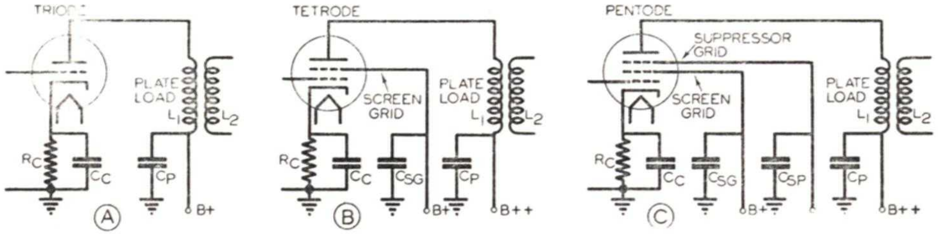

Fig. 2. Here are three applications of the general by-pass condenser rule. Observe that signal currents in the plate circuit are by-passed to the chassis after they leave the plate load, while screen and suppressor grid signal currents are by-passed to chassis after leaving their respective electrodes. In each case the cathode by-pass condenser provides a low-reactance path from chassis to cathode for signal currents.

Simple Signal Current Filters

Simple Condenser Filter. To understand why a simple condenser filter will not always give the desired results, consider Fig. *3A* where condenser C_F is connected across load resistor R_L. These two parts are fed from a source which provides both A.C. and D.C. voltage, but we wish to apply only D.C. voltage to the load resistor. The reactance of condenser C_F is low for A.C., but this does not solve the problem, because we still have the full A.C. generated voltage across the load. Parts in parallel all have the same voltage, and here the resistor and condenser are essentially in parallel with the A.C. generator because the resistance of the connecting wires and the internal resistances of the generators are negligibly small. The condenser has simply increased the load on the A.C. generator and caused more current to be drawn from it, without appreciably lowering the A.C. voltage across the load. Of course, if either generator had a high internal resistance, the increase in alternating current would cause most of the A.C. voltage to be dropped inside the generator, and little would appear across C_F and R_L.

Coil-Condenser and Resistor-Condenser Filters. Let us consider the filter circuit arrangement of Fig. *3B* first with only R_F connected (*CH* removed). We see that the A.C. voltage drop across C_F is applied across R_F and R_L in series. If R_F is large in ohmic value with respect to R_L, most of the A.C. voltage will appear across R_F, and very little across R_L. However, the D.C. voltage also divides between R_F and R_L in the same ratio as the A.C voltage, and R_F contributes no filtering action.

To get filtering action and maximum D.C. voltage across load R_L, we replace resistor R_F with choke *CH*. The choke has a much higher reactance to A.C. than R_L, so nearly all of the A.C. voltage is dropped across the choke. For D.C., the choke resistance is low compared to that of R_L, so most of the D.C. voltage appears across R_L.

Just as in Fig. *3A*, condenser C_F in Fig. *3B* is ineffective as a filter except when the generators have high internal impedance. We can make this condenser contribute to filtering action, however, by inserting a resistor at point x in Fig. *3B*. The alternating current flows through this series resistor and the low combined impedance of C_F and R_L, and most of the A.C. voltage drop now appears across the series resistor. The D.C. voltage divides between R_L and the series resistor, however, so we may not get enough D.C. voltage across load R_L if we use too large a series resistor for filtering purposes.

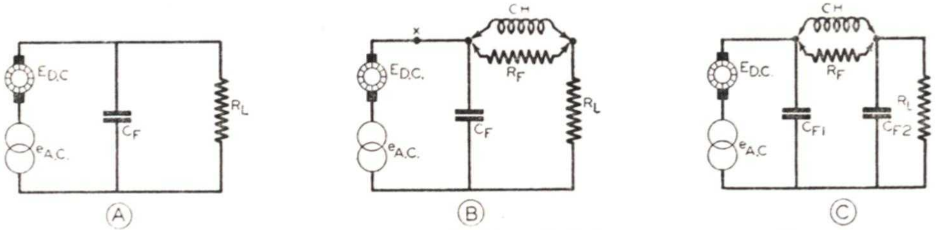

Fig. 3. The actions of the signal current filters commonly used in radio circuits are readily understood by studying these basic filter arrangements. Note the two-circle symbol for an A.C. generator; this symbol is widely used by radio and electrical men.

If high D.C. load voltage and adequate filtering are both required, a choke must be used at x in Fig. *3B* instead of a series resistor. This gives two choke coils and one condenser in the filter network, and is a highly effective arrangement because the chokes offer high impedance to A.C. but very little opposition to D.C.

Dual-Condenser Filters. In practical circuits the source resistance is usually appreciable, and here the filter arrangement shown in Fig. *3C* is highly effective. It has only one choke coil, and will work fairly well even with resistor R_F in place of the choke. Any A.C. voltage across C_{F1} is further reduced by the voltage-dividing action of high-impedance *CH* (or R_F) and low-impedance C_{F2}, so there is very little A.C. voltage across the load.

Pi or Low-Pass Filters. When the choke coil is used in the circuit of Fig. *3C*, we have a *pi filter* (so-called because on a circuit diagram it resembles the Greek letter π, which is pronounced "pie") or *low-pass filter* which can separate low frequency signals from high frequency signals. This filter has a resonant action at a definite frequency known as the *cut-off frequency;* signals below this cut-off frequency pass through the filter readily and enter the load, for the choke coil then has very little reactance and the condensers have such high reactances that there is little shunting effect on signals. At frequencies slightly above the cut-off value, resonant action prevents transfer of signals through the filter. Signals considerably above the cut-off frequency are blocked by the choke coil and passed by the condensers, and hence cannot reach the load.

The cut-off frequency value depends upon the inductance of the choke and the capacities of the condensers (which are usually of equal size). The cut-off frequency is easily found by considering the filter as a resonant circuit made up of an inductance equal to one-half the inductance of the choke coil and a capacity equal to that of one of the condensers in the filter, then determining the resonant frequency by the usual procedure for resonant circuits.

Practical Examples of Signal Current Filter Circuits. The tuned radio frequency amplifier circuit in Fig. *4A* contains two examples of the resistor-condenser filter shown in Fig. *3B*. Condenser C_{F1} provides a direct path to cathode for grid circuit R.F. currents, while the C_{F1}-R_{F1} filter combination prevents any A.C. voltages which may exist across R_C from affecting the grid of the tube (there may be small amounts of A.C. plate current and power pack ripple current flowing through R_C and developing A.C. components of voltage across it). What happens is this: C_{F1}, having a very low reactance, is in series with R_{F1}, a very high resistance, across R_C, so what little alternating current gets through R_{F1} produces only a negligible A.C. voltage drop between points *1* and *2* as it flows through C_{F1}. Only the desired steady D.C. voltage across R_C can act on the grid through R_{F1}. Remember this important fact: A signal current filter *will act both ways,* preventing signal currents which are in one circuit from getting out and preventing other alternating currents from getting in.

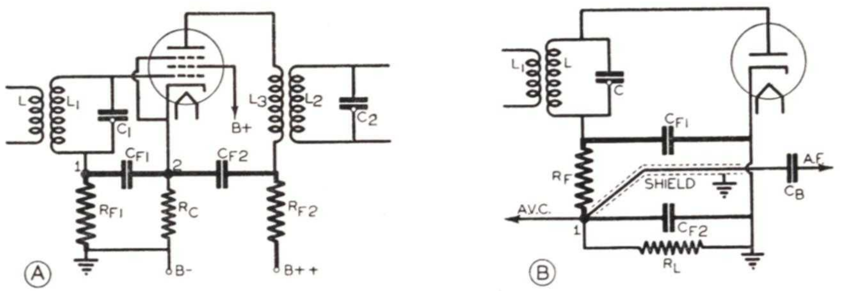

FIG. 4. The signal current filter is shown by heavy lines in each of these radio circuits.

In the same manner, signal current filter C_{F2}-R_{F2} prevents plate circuit signal current from getting into the power supply and prevents any alternating current in the power supply from getting into the plate circuit. Filter resistor R_{F2} naturally lowers the D.C. plate voltage a certain amount; if this reduction in voltage is undesirable, this resistor may be replaced by an R.F. choke coil. Unfortunately, this substitution of a choke coil only serves to prevent plate circuit signal currents from getting into the power supply; the choke coil is not effective in keeping low frequency power pack ripple currents out of the plate circuit unless an additional iron-core choke designed for this particular purpose is used in series with the R.F. coil. For effective two-way filter action, R_{F2} should be replaced by R.F. and A.F. choke coils in series. Because of the relatively high cost of choke coils, it is more economical to use a filter resistor and either increase the D.C. supply voltage or adjust the circuit to operate satisfactorily at a reduced value of plate voltage.

The diode detector circuit shown in Fig. *4B* contains a practical example of the dual-condenser filter represented by Fig. *3C*. The path taken by the *rectified* signal current is through the diode tube, input coil *L,* filter resistor R_F, and diode load resistor R_L. R.F. current is kept out of the diode load by the filter combination made up of C_{F1}, R_F and C_{F2}. In some circuits you will

find that C_{F2} is omitted, and the wire going from point *1* to the A.F. stage through blocking condenser C_B is surrounded by a grounded metal shield. This shield acts as a capacity to the chassis, and thus serves the double duty of substituting for condenser C_{F2} and shielding this lead from stray electrostatic and magnetic fields.

I have already pointed out that choke coils may be used in place of filter resistors. One important objection to the use of choke coils is the fact that their characteristics change greatly with the frequency. Wherever possible, non-inductive carbon or metallized resistors are therefore used as filter resistors, particularly in high-fidelity audio amplifiers and in the preselector stages of all-wave superheterodyne receivers, for their effects are the same at any frequency.

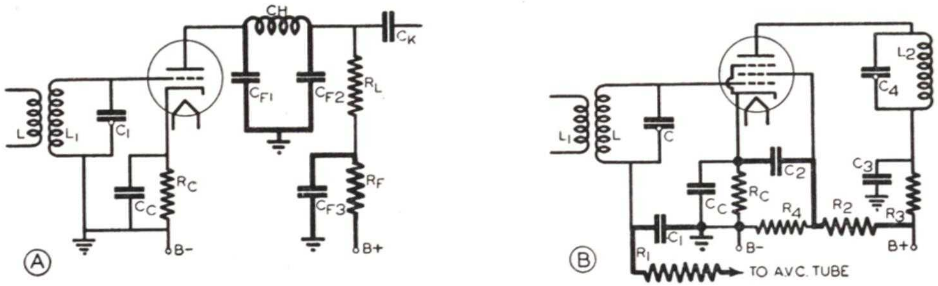

FIG. 5. Triode second detector circuit (*A*) and I.F. amplifier circuit (*B*) containing examples of signal current filters (shown in heavy lines).

The second detector circuit in Fig. *5A* is an example of a superheterodyne receiver stage where a pi or low-pass filter is used. The combination of C_{F1}, *CH* and C_{F2} forms a filter like that in Fig. *3C,* which definitely suppresses the I.F. signals while allowing direct current and low or audio frequency current to pass through. The desired modulation signal currents thus pass through load R_L and return to the cathode through by-pass condensers C_{F3} and C_C. The cut-off frequency for this filter can be any value lower than the I.F. value but higher than the highest modulation signal frequency being handled. The signal current filter made up of C_{F3} and R_F in Fig. *5A* serves to keep signal currents in the plate signal circuit and to keep power pack ripple current out of the plate signal circuit.

An I.F. amplifier circuit using a pentode tube and two resistor-condenser signal current filters is shown in Fig. *5B*. You can readily identify condenser C_C as the by-pass condenser for automatic C bias resistor R_C; this condenser also provides a low-reactance path from ground to cathode for all signal currents. You will also recognize combination R_1-C_1 as the A.V.C. filter for this stage; this filter has a two-way action, providing a path to ground for R.F. grid currents (thus keeping them out of the A.V.C. system) and preventing the A.C. components of A.V.C. voltage from entering the grid circuit. Filter R_3-C_3 forces the A.C. plate current to go to the chassis and then through C_C to the cathode instead of entering the power pack. Resistors R_2 and R_4 serve primarily as a voltage divider which provides the screen grid with the correct portion of the supply voltage, but R_2 also serves with C_2 as a filter which prevents screen grid signal currents from flowing through the supply lead and the power pack to the cathode. C_2 provides a direct path from screen grid to cathode for these currents.

D.C. Blocking Condensers

When the plate circuit of one stage is to be coupled to the grid circuit of a following stage and both stages have common supply terminals, the coupling device must be of such a nature that it keeps D.C. supply current out of the grid circuit of the following stage. (This discussion does not apply to direct-coupled amplifiers.) If this precaution were not observed, the grid would become positively charged with respect to its cathode, and correct operation would not be secured. When radio or audio frequency transformers are used as plate loads, the signal is transferred from one stage to another by induction and the D.C. component of plate current can flow only in the primary of the transformer, effectively solving this problem. When resistors or choke coils are used as plate loads, however, special means must be used to prevent D.C. supply current from entering the following grid circuit.

A universally used solution to this coupling problem is that shown in Fig. *6A*, where coupling condenser C_B provides a low-reactance path for signal currents between the two stages and effectively blocks any flow of direct current. The currents flowing through each part in this circuit are indicated. You can readily see that if there were a D.C. conductive path for electrons from point *2* to point *1*, electrons starting from point *3* (which is at ground or B— potential) would pass through grid resistor R_{g2} to point *2*, and then to point *1* and through resistors R_P and R_F to the B+ terminal of the power pack, making point *2* positive with respect to ground (point *3*) and thereby placing a high positive bias on the grid of the following tube.

Quite often an external D.C. voltage is to be applied to a tube electrode which is already connected to ground by a D.C. conductive path. The R.F. amplifier circuit in Fig. *6B* is an example; oftentimes an A.V.C. voltage must be applied to the grid of the tube, yet because the rotor of the tuning condenser is permanently grounded to the chassis and at the same time connected to one side of low-resistance coil L_1, an A.V.C. voltage applied directly to the grid would be shorted to ground through L_1.

One solution to this problem appears in Fig. *6C*. The A.V.C. voltage is applied to the grid of the tube through an A.V.C. filter in the usual manner, with resistor R_g inserted as shown to prevent the A.V.C. circuit from shunting to ground (through A.V.C. filter condenser C_F) the R.F. signal voltages produced across tuning circuit L_1-C_1. The value of R_g may be several hundred-thousand ohms; since the grid of the tube is negative at all times, it draws no current, and any current-limiting effects of resistors in the grid circuit are unimportant. In addition, D.C. blocking condenser C_B is required to prevent shorting out of the A.V.C. voltages by coil L_1. This is known as the *shunt feed* method of applying an A.V.C. voltage, for the A.V.C. voltage acts in parallel or in shunt with the signal input voltage.

Another solution to this same problem, used when the coil can be disconnected from the chassis, is the *series feed* method of applying the A.V.C. voltage, shown in Fig. *6D*. The A.V.C. lead is connected to the lower end of coil, L_1, through resistor R_F of the A.V.C. filter. A.V.C. filter condenser C_F serves as a D.C. blocking condenser in preventing the A.V.C. voltage from being shorted to ground, and at the same time provides the required low-reactance path from the coil to ground for R.F. signals.

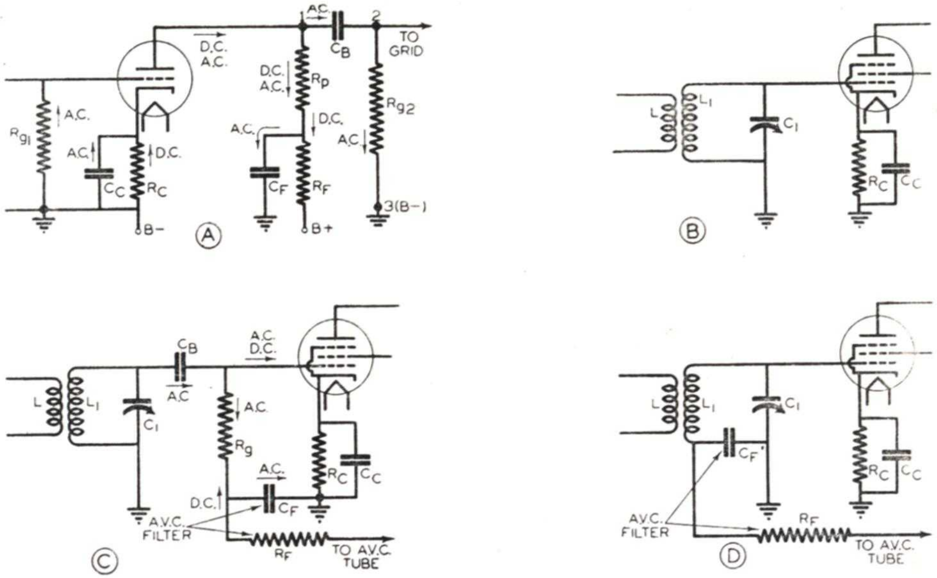

Fig. 6. Examples of circuits which require and use D.C. blocking condensers.

Importance of Proper Connections

The use of filter circuits to keep R.F., I.F. and A.F. currents out of the power supply is in itself no assurance that regeneration or degeneration effects will disappear. We still have to consider the problems of stray coupling between leads, common coupling between different circuits due to stray currents in the metal chassis, and common coupling between circuits due to stray currents in ganged variable condensers, for each of these defects can cause either regeneration or degeneration under certain conditions.

An engineer can sit down at a drawing board and, after making certain engineering calculations, design a radio receiver or an amplifier which has certain desired characteristics. It is quite another matter, however, to convert this design into an actual model which has these same characteristics. Regeneration and degeneration effects generally give the most trouble, making necessary considerable experimentation in order to determine the best locations for the various parts and connecting wires.

Long connecting wires from the grid to the grid input circuit, from the plate of a tube to the plate load, or from the screen grid electrode of a tube to its power supply terminal are to be avoided, for they can give trouble in the form of capacitive or inductive coupling between each other.

Quite often a receiver manufacturer will allow a certain amount of regeneration or degeneration to exist because it does not appear to be objectionable at the time, but will later be compelled to modify certain sections of the receiver because the undesired effects become too objectionable after the receiver has been in use for some time. This is why you will occasionally find receivers of the same model, but made at different times, with minor changes in connections and parts values. Furthermore, since Radiotricians are called upon to make these corrections on earlier receivers which have developed trouble, the practical importance of this problem of making proper connections is quite evident.

Proper Connections in a Single R.F. Stage. As a practical example, let us consider how connections should be made in a typical pentode R.F. amplifier stage, such as that represented by the schematic circuit diagram in Fig. *7A*. This diagram tells us that A.V.C. filter R_1-C_3 is used to keep A.F. signals out of the grid circuit, to delay the A.V.C. action, and to provide a low-reactance path from the grid circuit to the chassis for R.F. signals. By-pass condenser C_4 provides a low-reactance path for signal currents around C bias resistor R_C, while screen grid filter R_2-C_5 keeps screen grid signal current out of the power supply; plate supply filter R_3-C_6 does the same thing for plate circuit signal currents. This diagram does not show, however, how these signal currents actually travel between points *1*, *2* and *3* through the chassis to point *4*. The paths taken by these currents are quite important, for degeneration or regeneration may occur if the signals from the screen grid, plate and control grid get a chance to produce appreciable voltages and mix before they reach the cathode. (Although the signals mix in passing through C_4, the reactance of this condenser is so low that the undesirable voltages produce negligible regeneration or degeneration effects.)

The production design engineer, who must decide beforehand the best location for each connecting lead and for each part, might redraw the schematic circuit diagram of Fig. *7A* in the manner shown in Fig. *7B* in order to indicate that points *1*, *2* and *3* be connected directly to point *4*. Doing this prevents the screen grid, control grid and plate signal currents from wandering through the chassis and mixing together before reaching point *4*. All by-pass condensers in a single R.F. stage should be connected to a common point in the stage in order to prevent undesirable direct coupling between the different circuits in the stage.

The arrangement of connections shown in Fig. *7B* may insure freedom from troubles due to improper direct connections, but we can still have trouble due to capacitive or inductive coupling between leads. Grid and plate leads in an R.F. stage must be kept as short and as far apart as possible in order to prevent capacitive and inductive feedback of signals from the plate circuit to the grid circuit. Suppose that, through faulty chassis layout, plate lead *z* is placed close to control grid lead *x*; this would allow signal feedback from the plate circuit to the grid circuit, causing either regeneration or degeneration. Keeping the input and output leads in their proper places, as far away from each other as possible, is a highly important duty of the radio apparatus manufacturer; since the exact positions of connecting wires are seldom shown in radio receiver service manuals, it is essential that you be familiar with approved methods of making actual connections.

Actual chassis connections for the pentode R.F. amplifier stage of Fig. *7A* are shown in Fig. *7C*, as they would appear when looking at the bottom of the chassis. The input and output coils with their trimmer condensers are, of course, on the top of the chassis, as also is the connection from the input tuned circuit to the top cap of the tube. Take particular notice of the fact that the control grid lead *x* and plate lead *z* do not run close to each other at any point; in fact, one is above the chassis and the other is below.

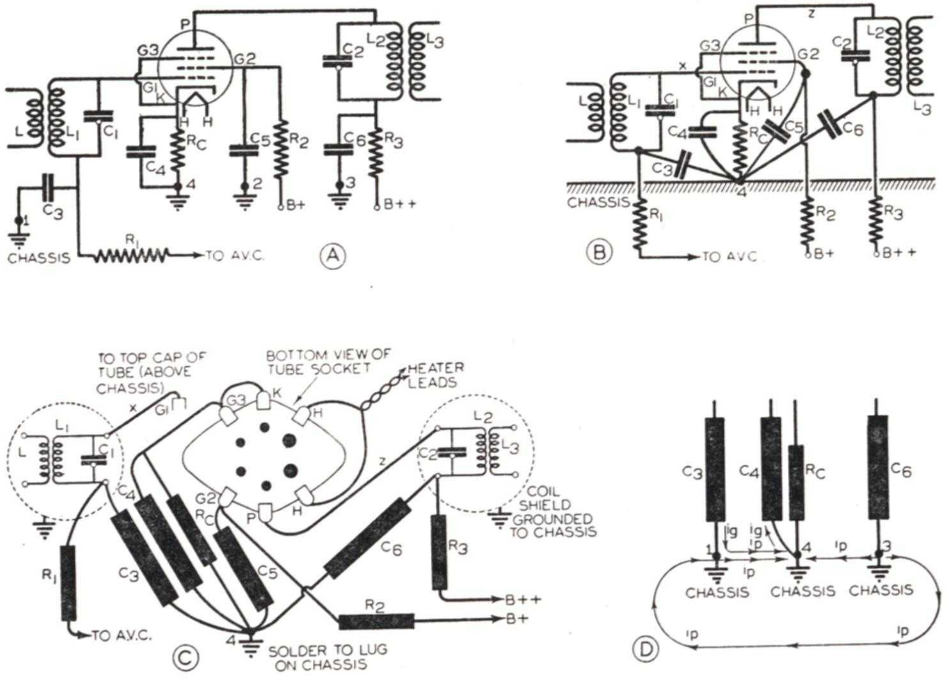

Fig. 7. An ordinary pentode I.F. amplifier circuit appears in its simplest form in the schematic diagram at *A*. Diagram *B* shows actual connections of by-pass condensers to a common point, but still in schematic form. Diagram *C* shows actual connections of parts on the chassis, while *D* shows how improper grounding of by-pass condensers to the chassis can result in interfering currents.

Effects of Stray Chassis Currents. Suppose that instead of making connections as shown in Fig. *7C*, points *1*, *3* and *4* were simply connected to the nearest convenient points on the chassis, as indicated in Fig. *7D*. Now we would expect the grid circuit signal current i_g to flow from point *1* through the chassis to point *4*, and A.C. plate current i_p to flow from point *3* through the chassis to point *4*. This is what actually takes place, but the A.C. plate current, which is many times greater than the grid current, spreads out over a wide path through the chassis in traveling from point *3* to point *4*. One possible curved path is indicated in

Fig. *7D;* notice that now some of the A.C. plate current i_p is flowing over the same path as the grid circuit signal current i_g. The A.C. plate current which takes the curved path causes an additional A.C. voltage drop between points *1* and *4* in the grid circuit, and this may cause undesirable regeneration or degeneration, depending upon the phase relationship between the signal currents involved.

If the grid by-pass condenser in a following stage is connected by mistake to a convenient point on the chassis, this signal current can likewise wander through the chassis, with one of its many possible paths being from point *1* to point *4* in Fig. *7D.* This current can likewise cause undesirable regeneration or degeneration, depending upon the phase relationships of the currents.

Courtesy Solar Mfg. Corp.

Although you ordinarily think of power pack filter circuits whenever electrolytic condensers are mentioned, here is an electrolytic condenser which is widely used to keep audio signal currents in correct paths. It is a low-voltage, high-capacity tubular dry electrolytic, and is used to by-pass a.f. currents around cathode resistors in the a.f. amplifier stages of radio receivers.

If it is desirable from a production viewpoint to connect points *1* and *3* directly to the chassis, as indicated in Fig. *7D,* a length of heavy copper wire running from point *1* to point *4* and then to point *3* will provide a single path for all these A.C. currents, keeping them from straying through the chassis. Since this heavy wire will have low resistance, the current will take this path in preference to the high-resistance path through the metal chassis. You will occasionally find this practice followed in radio receivers; a single heavy bus wire (copper wire having a square cross-section) is run from point *1* to point *4* to point *3* of one tube to point *1* to point *4* to point *3* of the following tube and in turn to each following tube. The connection must be made in this logical order if interference between currents is to be prevented.

Stray Currents in Ganged Variable Condensers. The ganged variable condenser in a sensitive modern all-wave receiver will generally have three tuning sections, with the rotors grounded (theoretically, at least) to the chassis through the frame of the condenser, as shown schematically in Fig. *8A.* There will be a connection from each stator section to the grid of a tube and to a tuning coil.

With the stator sections so close to each other on the condenser unit, you can readily see how signals in one section might affect an adjacent stator section, causing feed-back effects. To eliminate this possibility, shielding plates are usually placed between the stator sections, these plates being grounded to the frame of the condenser and therefore to the chassis. (Electrostatic shielding of this type will be taken up later in this lesson.)

The average technician fails to realize that the current in each resonant circuit must flow through the rotor shaft in order to get to the condenser frame and then to the chassis. The construction of the rotor plate assembly is such that this path has appreciable resistance, and a certain amount of regeneration or degeneration occurs when different signal currents flow through the same section of the rotor.

In the circuit of Fig. *8B,* for example, signal currents through condenser section C_2 can either flow through the apparent rotor resistance R_2 of this condenser and then through rotor resistance R_3 of condenser C_3 to ground, or can simply flow through the rotor resistance R_1 of condenser C_1 to ground; in either case there will be interference between signal currents. In order to eliminate this trouble, it is necessary to provide low-resistance paths to ground for the signal currents of each rotor section. Thus you will often find wiping contacts on each side of a rotor section, with each pair of contacts connected together and also connected directly to the chassis, as shown in Fig. *8C.* A better connection is from the rotor wiping contacts directly to the low or grounded R.F. terminal of the tuning coil associated with a rotor section.

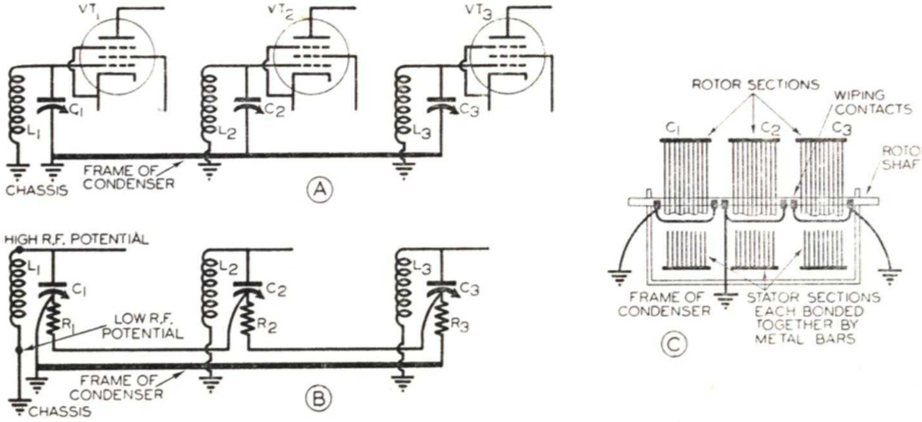

FIG. 8. Connections for a typical three-section ganged variable condenser appear at *A*. The effective locations of rotor shaft resistances are shown at *B* (curved arrows represent rotors), while one method used to offset the effects of rotor resistance and eliminate stray currents is shown at *C*. R_1, R_2 and R_3 are not actual resistors, but represent resistances existing in each rotor section because of its mechanical construction.

Since the currents flowing in the rotor sections are resonant stepped-up currents, they may often be quite large, making the stray currents appreciable in relation to desired signal currents. Rather elaborate precautions must often be taken to eliminate these stray currents; a study of the gang tuning condensers in a few modern all-wave receivers will reveal the exact manner in which low-resistance paths to ground are provided for each rotor section.

Shields for Electric Fields

Having seen how interfering currents can get into circuits by actually flowing over undesired conductive paths, we are ready to consider how interfering currents can invade a circuit even when there are no direct wire connections. When the medium by which the interfering signals enter is an electric field, we call the action *electrostatic induction,* and when a magnetic field is to blame, we call it *electromagnetic induction.* We will consider electric fields first.

How Electric Fields Affect Grid Circuits. The grid or grid lead of a vacuum tube is particularly susceptible to stray electric fields, for extremely small induced A.C. grid voltages can produce strong A.C. plate currents. The action is as follows: When the grid lead of a vacuum tube is located in the electric field which surrounds a highly charged object, variations in the electric charge (potential) of the object will cause the electric field to vary correspondingly, and this varying electric field will influence the free electrons in the grid circuit. When the object is negatively charged, it will repel the grid electrons; when the object is positively charged, it will attract the grid electrons (like charges repel, and unlike charges attract). If the object is being charged by an A.C. potential, the free electrons in the grid circuit will move back and forth to produce an alternating current of the same frequency.

Sources of Electric Fields. The plate of a vacuum tube is one object which can have a varying potential and produce an electric field which affects other circuits. The electric field associated with a power transformer or audio transformer can also induce currents in nearby tubes and in conductors. The stator plates of one section of a variable condenser can produce varying electric fields which induce interfering currents in another stator section or in connecting leads. There will also be an interaction of electric fields when plate leads run near grid leads. These are just a few typical examples of how interfering currents are produced by stray electric fields. These interfering currents can result in regeneration, in degeneration or even in undesirable modulation of an R.F. signal, depending upon circuit conditions. Excessive regeneration, which results in a hissing noise in the loudspeaker or even in squeals due to oscillation, is easily recognized as being due to undesired coupling between circuits. Likewise, a 60 or 120 cycle hum modulation can be recognized and often traced to undesirable coupling between a power supply part and some signal circuit.

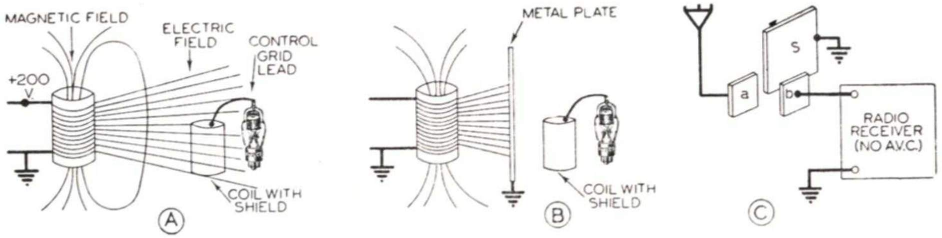

FIG. 9. These diagrams show how an electric field can affect electrons in the grid circuit of a tube, and how a metal plate serves as a shield for electric fields or electric lines of force.

Shielding of Coils. The electric field around a coil which is carrying a current can be represented as shown in Fig. *9A*. When this electric field passes near the control grid lead of a vacuum tube, the electrons in this lead will move back and forth in accordance with variations in the current through the coil, and consequently an interfering current will be induced in the control grid lead.

If a metal plate is inserted between the coil and the exposed grid lead of the tube, as indicated in Fig. *9B*, this metal plate will serve as a shield which prevents the electric fields (lines of force) from going any farther. Only materials which are good conductors of electricity will serve as shields for electric fields; insulating materials have little or no blocking effect upon an electric field.

The effectiveness of a shield in suppressing an electric field is easily demonstrated if you have access to a radio receiver which does not have A.V.C. Couple the receiver to the antenna system in the manner shown in Fig. *9C*, so that the only connection to the antenna is by capacity coupling between metal plates *a* and *b*. With plate *a* removed, tune the receiver to a station which can just barely be heard. Now as you bring plate *a* near plate *b*, the volume will increase. Inserting a third metal plate *S*, larger in size, between plates *a* and *b* without touching them will have no effect on volume, for plate *S* merely relays the electric charges from plate *a* to plate *b*. When plate *S* is grounded, however, the electric field set up by plate *a* is grounded through *S*, and the volume will drop to the point where it is just barely audible. *This little demonstration shows clearly the importance of grounding an electric shield* in radio apparatus.

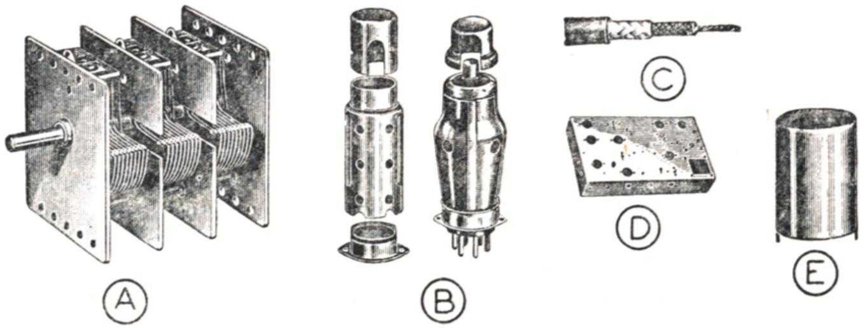

FIG. 10. Examples of electric shields used for radio apparatus.

Practical Data on Electric Shields. The use of metal plates as shields between interfering parts is an old idea in radio, and this practice is followed even today in isolating the sections of many ganged variable condensers. Metal plates are entirely impractical, however, for shielding other parts in a receiver, as an electric field radiates in all directions and can affect many parts simultaneously.

The solution to the problem of suppressing electric fields lies in surrounding with a metal case the coil or other part which produces the field in order to prevent spreading of the field. Parts which may be affected by electric fields are surrounded with metal shields in much the same manner. Thus, grid leads are surrounded by flexible metal sleeves (with insulation between the sleeve and the grid wire to prevent a short circuit), metal shields are used over glass tubes, or tubes which have all-metal envelopes are used to overcome the effects of electric fields.

Typical metallic shields which have been found effective in preventing interference by electric fields are shown in Fig. *10*. The metal plates used between sections of a ganged variable condenser are illustrated at *A*. Two types of metal shields for glass tubes appear at *B*. At *C* is shown a shielded wire; an ordinary insulated wire is covered by a flexible metallic braid or metallic loom, and the metal is in turn covered by a layer of insulation. Sometimes this outer layer of insulation is omitted, and sometimes there may be two or more insulated wires inside the metallic loom.

In addition to supporting the various parts, the chassis of a radio receiver also serves as a shield which is effective in preventing interference between parts above the chassis and those below the chassis; a typical chassis made of heavy gauge sheet metal is shown at *D*.

An example of an aluminum shield used for R.F. coils and R.F. transformers appears at *E*. In all cases it is essential that the shield be grounded to the metal chassis of the receiver at several points.

Shielding is so important to the operation of a high-gain, high-quality radio receiver that totally exposed parts (except resistors) are becoming quite rare. Paper condensers are automatically shielded if that lead marked "outer foil," "grounded end," or "ground" is connected to the chassis; a great many types of electrolytic condensers are made with metal shields, these being automatically grounded by bolting the unit to the chassis. The envelopes of all-metal tubes are likewise grounded automatically by inserting the tube in its socket, for one prong of the tube is always connected to the metal envelope, and the socket terminal for this prong is usually grounded.

Electromagnetic Shields

Stray magnetic fields, which are produced by coils or wires carrying varying electric currents, can induce interfering voltages in other coils or wires. These induced voltages are especially troublesome in grid circuits.

Two distinct electromagnetic shielding problems arise in the construction of radio equipment: *1*, the elimination of interference due to parts which carry low-frequency power supply currents or A.F. signal currents; *2*, the elimination of interference produced by parts which carry R.F. or I.F. currents.

Shields for Low-Frequency Magnetic Fields. In the case of magnetic fields which vary at a low frequency, the solution is simple. The part in question, usually an A.F. or power line frequency choke or transformer, is placed in an iron or steel housing which is so designed that leakage magnetic fields will flow through this housing and return to their correct paths instead of straying through the receiver and making trouble. Surrounding a coil with iron or steel lessens the temptation for lines of force to take high-opposition paths through air; iron or steel housings or shields are therefore widely used for low frequency coils and transformers.

Shields for High-Frequency Magnetic Fields. At frequencies above about 50 kc., it is not necessary to use an iron or steel housing for shielding purposes; in fact, *materials with good conductivity*, such as aluminum and copper will give better shielding effects than poor-conductivity iron and steel.

You can perform a simple experiment which will show how R.F. magnetic fields are affected by shields. Two coils, L_1 and L_2, are connected as shown in Fig. *11*. Any air-core coils will do; the numbers of turns are not important; Coil L_2 is connected to the antenna and ground terminals of a radio

receiver which does not have A.V.C. and which is tuned to a strong local station. Coil L_1 is connected to the antenna and ground, as indicated. Antenna current flowing through L_1 sets up a varying R.F. magnetic field which induces an R.F. voltage in coil L_2, and signals are therefore transferred to the receiver input.

Now insert between coils L_1 and L_2 a reasonably large copper, brass or aluminum plate, or place an ordinary aluminum cooking pot or frying pan between the two coils. You will find that this prevents transfer of the magnetic field from one coil to the other, and therefore prevents the local station from being heard. If this metal plate is grounded, it will also act as a shield for electric fields.

The action of the metal shield in Fig. *11* can be explained as follows: In attempting to pass through the conductive metal plate, the varying magnetic flux sets up very small circulating currents in the metal plate. You can consider this plate as being made up of many small circular metal rings, each of which is a complete closed circuit for electrons. The varying magnetic flux induces a voltage in each of these closed circuits in such a manner that the currents flowing through the circuits produce magnetic fields to oppose the original magnetic fields; this is simply Lenz' Law, with which you are already familiar. The opposing magnetic flux repels the original flux, sending it back and thus preventing the original flux from penetrating the metal shield. The circulating currents produced in the metal shields are called *eddy currents*. Of course, a certain amount of power is wasted when eddy currents flow in a conductor, but if the shield is not placed too close to the strongest part of the magnetic field, the loss will be negligible.

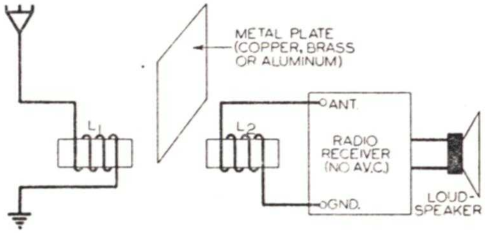

Fig. 11. In this experiment, a conductive metal plate inserted between the two coils prevents R.F. signals from reaching the receiver.

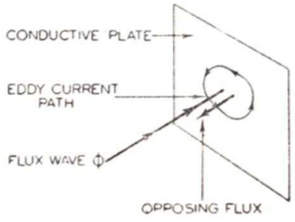

Fig. 12. How eddy currents in a metal plate can set up an opposing flux.

High-grade R.F. and I.F. coils are usually placed in aluminum or copper cans, but copper-plated steel housings are also used as shields for coils. Aluminum and copper are good conductors of electricity, and therefore allow larger eddy currents to flow; these currents in turn produce stronger opposing magnetic fields to keep the original flux from passing out of the can. By placing the shield a reasonable distance away from the coil (at least one-half the diameter of the coil), little loss of signal power is incurred. Since the shield in effect acts as a larger number of short-circuited secondary windings on the coil, the main flux of the coil is reduced and the inductance of a shielded coil is therefore lower than that of an unshielded coil. The relationship of the original flux, the eddy current rings and the opposing flux are indicated in Fig. *12*. Typical shielded coils are illustrated in Fig. *13*.

Positioning of Parts for Minimum Interference

When shielding of parts is impractical or is not completely effective, interfering effects can be kept at a minimum by proper positioning of those parts and wires which are most affected. A review of the nature of magnetic fields and their voltage-inducing characteristics will reveal the best positions for various parts and wires.

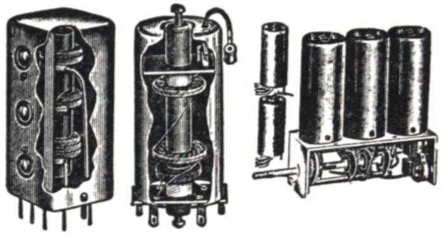

FIG. 13. Examples of shielded R. F. coils.

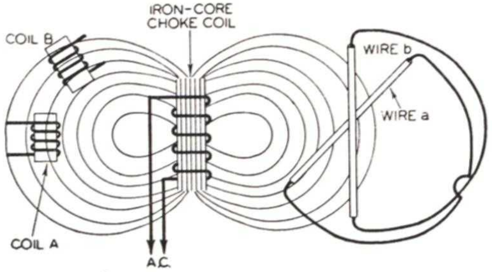

FIG. 14. The position of a coil or wire in a magnetic field determines whether or not a voltage will be induced.

The nature of the magnetic field in the vicinity of a coil is indicated in Fig. *14*. For purposes of simplicity, an iron-core choke coil having open core ends was chosen. When a wire which is a part of a closed electrical circuit is placed in this magnetic field in such a way that the field cuts across the wire (or loops through the closed circuit formed by the wire), as is the case for wire *a* in Fig. *14*, a voltage will be induced in the wire. When the wire is placed in position *b* (Fig. *14*), the magnetic field will be parallel to the wire instead of cutting it or linking through the closed circuit, and no voltage will be induced. Thus you can see that for minimum interference, a wire should be parallel to the magnetic lines of force in its vicinity.

When a coil is placed in the magnetic field produced by the iron-core choke in Fig. *14*, the relative positions of the two coils will determine whether or not a voltage is induced. For example, coil *A* in Fig. *14* is placed with its axis parallel to that of the choke coil, and hence the magnetic field links through coil *A*, producing an induced voltage. Observe that the magnetic lines of force which pass through coil *A* are parallel to the axis of the coil. The axis of coil *B*, however, is at right angles to the magnetic lines of force; in this case no flux flows through the turns of the coil and consequently there is no voltage induced.

Positioning of Wires. When it is necessary to place two wires close together, and one of the wires carries a varying current which can produce a varying magnetic field and in turn induce an interfering current in the other wire, the two wires should be placed at right angles to each other in the manner shown in Fig. *15A*. Doing this makes the magnetic lines of force produced by wire *x* cut across wire *y* twice in opposite directions, with the result that the two voltages induced in *y* cancel each other and have no effect upon the circuit of which wire *y* is a part. For example, one line of force produced by wire *x* may cut wire *y* at point *1* at a certain instant, producing in *y* an induced voltage having a certain polarity, but at the same instant this line of force will be cutting wire *y* in the opposite direction at point *2*, producing a voltage of opposite polarity at *2*. Placing wires at right angles to each other in this way also reduces interaction of electric fields.

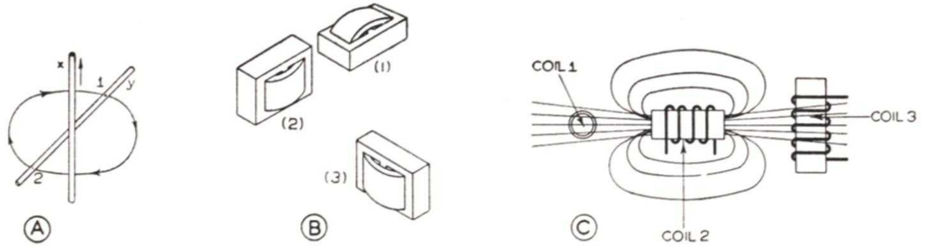

FIG. 15. Interfering currents due to electromagnetic induction are a minimum when wires, iron-core devices and coils are positioned at right angles to each other, as shown here.

Positioning of Coils. Coils and transformers should be positioned in such a way that their main magnetic field paths are at right angles to each other, as indicated in Figs. *15B* and *15C*, and should be as far apart as possible from circuits which are most affected. This rule is, of course, only approximate, for the fields produced by these devices may be considerably distorted. Final positions for minimum interaction can be determined by experimentation; in the case of audio and power transformers, this can be done by feeding an A.F. or power line voltage to one coil and connecting a pair of headphones either directly across the other coil or through a separate audio amplifier which boosts the voltage and gives more positive results. Adjust the position of either transformer until minimum hum is heard in the headphones. In actual radio receivers you can, of course, adjust the position of the transformer until minimum hum is heard.

Twisting of Power Supply Leads

Having seen how the low-frequency magnetic fields which are produced by power transformers and power pack filter chokes can be prevented from straying, we are ready to consider how the connecting leads to these parts can be prevented from setting up interfering magnetic fields. The power line leads which pass through the OFF-ON power switch to the power transformer are one possible source of trouble, and the low voltage, high current A.C. leads to the filaments of all tubes are another common cause of trouble. A study of the magnetic fields produced when two wires are close together will show how these magnetic fields can be suppressed.

Figure *16A* shows two parallel wires, W_1 and W_2. Alternating current flows out over one wire and back to its source over the other, but at any instant of time the electron flow is in opposite directions as indicated. The magnetic lines of force produced by these currents have circular loops as indicated, with loops x produced by W_1 and loops y produced by W_2.

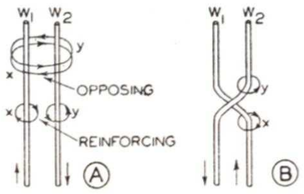

Fig. 16. Magnetic fields produced by two wires which carry the same current in opposite directions.

Some of the magnetic loops will enclose both wires; notice that when this occurs, the magnetic lines of force will be in opposite directions and will cancel. Some of the magnetic loops will surround only their own wires, and in these cases the magnetic lines of force produced between the wires will all be in the same direction, and will reenforce each other.

Separating the wires allows more of these magnetic lines of force to pass between the wires and reenforce each other, and consequently the external magnetic field in the vicinity of the two wires becomes stronger. Placing the wires closer together, on the other hand, forces more of the magnetic lines of force to encircle both wires and cancel each other, thus reducing the strength of the external field. Twin conducting leads should therefore be very close together if interfering magnetic fields are to be reduced to a minimum.

Even greater reduction in the external magnetic field produced by two current-carrying wires is possible when the wires are twisted together. The wires must, of course, be insulated in this case in order to prevent shorting them together. Figure *16B* shows how twisting or transposing leads W_1, and W_2 makes the individual flux paths x and y take opposite directions. In the vicinity of the wires these lines of force do not entirely interlock and cancel, but at a distance from the leads they actually do cancel and greatly reduce the external magnetic fields.

The more twists or transpositions there are in a given distance for two wires, the more reduction there is in external or stray magnetic fields. Incidentally, this reduction in the external magnetic field actually reduces the inductance of the conductors (any two wires which are close to each other and in the same circuit have a certain amount of inductance due to the fact that they form a single-turn coil).

Now you can understand why filament leads in radio apparatus are often twisted together or run very close together, and you can likewise understand why the power line leads to the power transformer primary are also twisted or placed close together. In some receivers, particularly those having low A.C. filament currents, manufacturers have found it unnecessary to twist filament wires or run them close together; elaborate precautions are needed only when trouble is actually encountered.

You will usually find that the power transformer is located at a point on the chassis very close to the place where the power line cord enters. The power switch, however, is usually located at the front of the chassis; the two leads running to it are usually quite long, and hence should be twisted together for minimum magnetic effects.

There is still a certain amount of leakage magnetic flux even when leads are twisted, and therefore filament and power supply leads should be kept as far as possible from the grid leads in the first stages of a receiver or amplifier. Even extremely weak interfering signals entering these stages may become appreciably strong after amplification by the entire system.

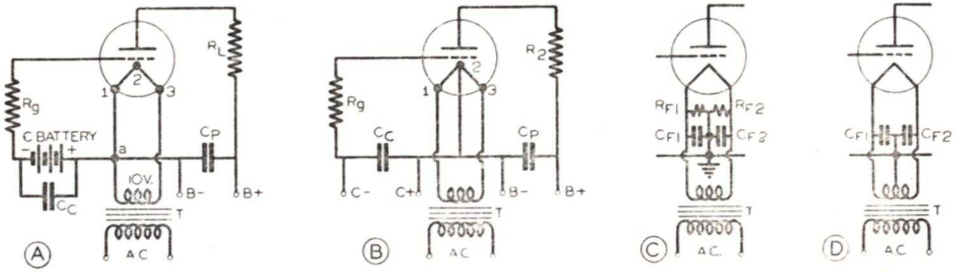

Fig. 17. When a filament type tube is being supplied with an A.C. filament voltage, as at *A*, the method shown at *B*, *C* or *D* is used to prevent the A.C. filament voltage from affecting the grid or plate circuits.

Center-Tapped Filament Connections

The importance of preventing alternating current in filament leads from affecting signal circuits by magnetic induction has already been pointed out; it is just as important to prevent alternating current in the filament itself from affecting the signal circuits and to prevent filament leads from providing conductive paths for signal currents.

With the heater-type tubes which are so widely used in radio receivers at the present time, there is no direct connection between the filament and the cathode; if there is no leakage between these two elements, there will be no chance for signal currents to get to the filament circuit and for power line A.C. to get out of the filament circuit into signal circuits.

In the audio stages of radio receivers (particularly the power stages) and in the R.F. stages of radio transmitters, filament type tubes are still widely used; here the filament serves also as cathode, and hence preventive measures must be taken.

Let us first see what happens when we connect a filament-type tube as indicated in Fig. *17A*. Consider a simple circuit like that in Fig. *17A*, where a C bias battery provides the normal negative bias voltage for the grid of the tube and the filament is fed with an A.C. voltage of, let us say, 10 volts. The grid and plate return leads for signal currents go to point *a* on one filament lead. Point *2*, at the electrical center of the tube filament, can be considered as the cathode of the tube, even though all points on the filament are emitting electrons. (For each point on the filament which is more negative than point *2* at any instant, there will be another point which is an equal amount more positive than point *2*, regardless of the direction of current flow; as a result, the average of the voltage values between the grid and each point on the filament will equal the voltage between the grid and point *2*, and likewise the average of all filament-to-plate voltages will equal the voltage between the plate and point *2*.) The plate current will, therefore, be determined by the potential between point *2* and the grid (the grid bias voltage) and by the potential between point *2* and the plate (the D.C. plate voltage).

We can readily see, now, that the effective grid voltage will be the C battery voltage plus the voltage drop between points *1* and *2* on the filament. With 10 volts A.C. applied between points *1* and *3*, there will be a 5 volt A.C. drop between points *1* and *2*. This voltage drop will act in series with the C battery voltage insofar as the grid is concerned, making the grid bias voltage alternately 5 volts greater and 5 volts less than the battery voltage. Naturally this A.C. voltage of 5 volts applied to the grid will cause the plate current to vary correspondingly. The A.C. voltage drop will likewise act in series with the B battery voltage in determining the effective plate voltage, but the variations in voltage will obviously be more serious in the grid circuit because of the high amplification of the tube. Clearly the arrangement in Fig. *17A* will result in excessive A.C. hum interference.

A theoretical solution to this problem is indicated in Fig. *17B*, where the A.C. filament voltage is eliminated from the signal circuits simply by connecting the plate and grid return leads directly to point *2* by means of a tap on the filament. Since few if any tube filaments are made with center-tap connections, this solution cannot be utilized in practice.

The practical solutions to this problem, indicated in Figs. *17C* and *17D*, involve the use of external electrical mid-taps between the two filament leads. These mid-taps can be provided by a center-tapped resistor, as in Fig. *17C*, or by a center-tapped filament winding, as in Fig. *17D*. Often the mid-tap on the resistor is made variable, so it can be adjusted to compensate for unbalanced filaments and other conditions. When filament-type tubes are used in radio frequency amplifiers, bypass condensers are generally connected between the mid-tap and each filament lead to provide low-reactance paths to either filament terminal of the tube for signal currents; in the case of Fig. *17D*, these condensers also serve to prevent signal currents from taking the path through the filament winding of the power transformer.

Analysis of Signal Current Circuits in a Typical Radio Receiver

The complete schematic circuit diagram of a typical 5-tube superheterodyne receiver is shown in Fig. *18* just as you might find it in the service manual for the set. We will study this diagram in detail, first tracing the paths of signal currents, then locating and identifying the various extra parts used by the designer to keep signal currents in their correct paths. Having done this, we will analyze the chassis layout of the receiver to see how the effects of stray electric and magnetic fields are minimized by proper placement of parts. This analysis will not only serve to summarize for you the many practical facts covered in this lesson, but will also give you additional experience in reading circuit diagrams.

A practical radio man is able to read a circuit diagram like that in Fig. *18* almost at a glance simply because he has learned to **consider only** the important fundamental signal circuit parts, neglecting the various resistors and condensers which keep signal currents in their correct paths, and neglecting the power supply leads. In Fig. *19* are shown only those parts which serve to identify the various stages of this receiver circuit; we will study this at first, in preference to the complete diagram in Fig. *18*, for you are not as yet expected to be able to eliminate the less-important parts mentally.

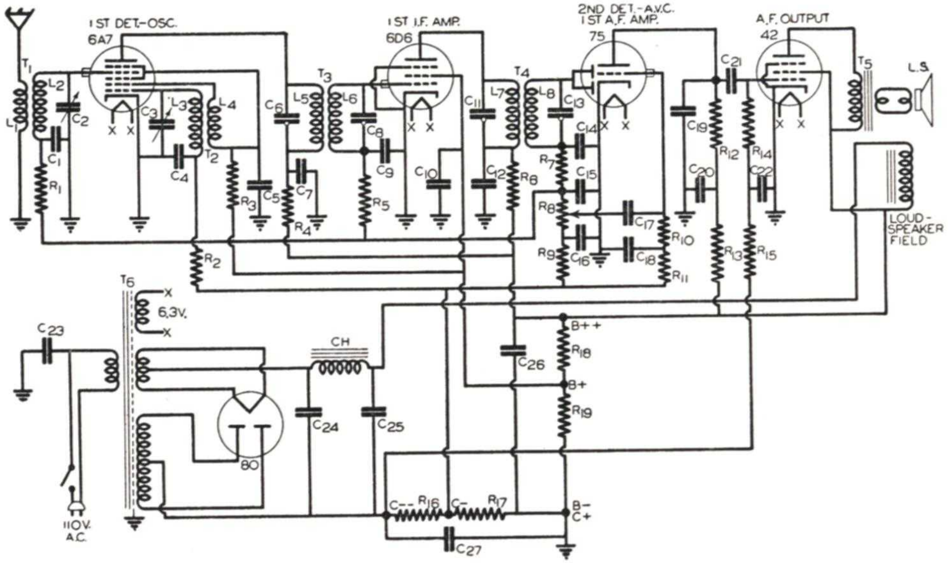

FIG. 18. Complete schematic circuit diagram of a representative 5-tube superheterodyne receiver. This circuit is presented here only to show circuit functions and illustrate the filtering and by-passing methods described in this book; it is not intended for constructional purposes, and does not represent any one particular manufactured receiver.

We start at the upper left in Fig. *19*, since the upper part of a radio circuit diagram is invariably arranged to read **from left to right. The R.F. signals picked up by the antenna are transferred to a grid of the first tube by T_1, which we recognize as a tuned-secondary antenna transformer. The first tube has five grids and is therefore a** pentagrid converter serving as mixer, first detector and oscillator. The first two grids of the tube act with parts C_3, L_3 and L_4 as an oscillating circuit which produces the desired local R.F. carrier to mix with the incoming R.F. signal and produce in the plate circuit of this 6A7 tube the desired I.F. signal.

Adjustable condensers C_6 and C_8 identify T_3 as an I.F. transformer which passes on this I. F. signal to the 6D6 first I.F. tube for amplification, while I.F. transformer T_4 transfers the amplified I.F. signal to the diode section of the type 75 tube. Here you will recognize the conventional second detector-A.V.C. arrangement, with diode current developing across the detector load the desired A.F. component and a D.C. component of voltage for A.V.C. purposes. The first detector and the I.F. amplifier are A.V.C.-controlled for their control grid leads do not return directly to their respective cathodes.

The A.F. signal is fed through coupling condenser C_{17} to the grid of the triode section of the 75 tube, which consequently acts as an A.F. amplifier stage. The value of the A.F. voltage which is fed to this first A.F. stage is controlled by the setting of manual volume control potentiometer R_8. The amplified A.F. signal is transferred to the type 42 output tube through resistance—capacitance coupling, and the A.F. output of this tube is fed to the voice coil of the dynamic loudspeaker through output transformer T_5.

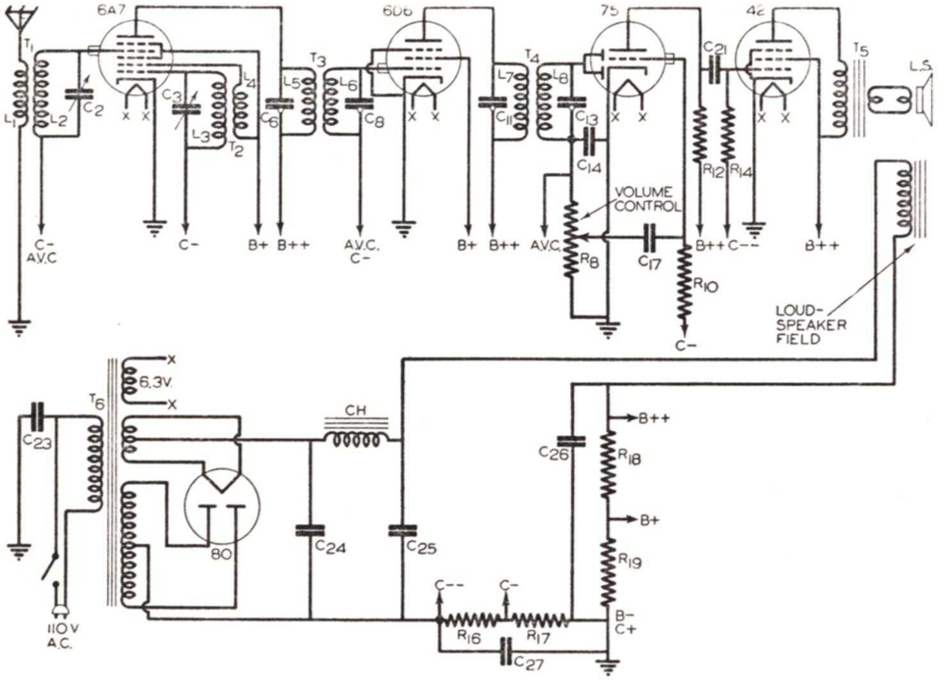

Fig. 19. Simplified version of the 5-tube superheterodyne receiver circuit shown in Fig. *18*.

D.C. voltages for the various tube electrodes are supplied by the power pack, made up of power transformer T_6, a type 80 full-wave rectifier tube, a filter system containing C_{24}, filter choke *CH*, C_{25}, the loudspeaker field (which serves also as a filter choke) and C_{26}. Voltage divider resistors R_{16}, R_{17}, R_{18} and R_{19} then provide the required values of B and C voltages, with C_{27} providing additional filtering for the C voltages.

Now that we are familiar with the general function of each stage in our receiver circuit, we can return to Fig. *18* and try our skill at identifying the various by-pass condensers and signal current filters which must be added to the basic circuit of Fig. *19* in order to secure satisfactory performance. We see immediately that C_1 and R_1 act as the A.V.C. filter for the first detector, for R_1 connects to a point in the load circuit of the diode second detector. C_1 also serves to provide a path to ground and cathode for grid circuit R.F. signals, and to prevent shorting to ground of the D.C. A.V.C. voltage.

Next we come to the R_2-C_4 combination. Since R_2 connects to the C— point of the power pack voltage divider, we know this is not an A.V.C. filter; it is therefore a simple resistor-condenser signal current filter, which keeps oscillator R.F. signal out of the power pack. C_4 also permits application of the C bias voltage to the grid without interrupting the continuity of the oscillator tank circuit C_3-L_3 for R.F. signals.

R_3-C_5 is likewise a signal current filter, serving to keep screen grid (grids 3 and 5) and oscillator plate (grid 2) R.F. currents out of the power pack and at the same time by-pass these signal currents to the cathode of the 6A7 tube.

R_4-C_7 is a signal current filter which by-passes plate signal currents of the 6A7 tube to its cathode and at the same time keeps these currents out of the power pack.

R_5-C_9 are readily recognized as another A.V.C. filter once you trace connections from R_5 to the second detector.

C_{10} is clearly the screen grid by-pass condenser for the first I.F. amplifier.

R_6-C_{12} form a signal current filter which by-passes plate signal currents of the first I.F. tube to cathode and keeps them out of the power pack.

Dual-condenser filter combination C_{14}-R_7-C_{15} serves to keep R.F. current out of diode detector load R_8 by providing low-reactance paths to cathode for this current. C_{16} and R_9 together serve as a signal current filter which permits application of normal C bias (developed across R_{17}) to the 6A7 and 6D6 A.V.C.-controlled tubes while preventing power pack hum currents from reaching these tubes and at the same time keeping signal currents out of the power pack.

C_{17} is simply an A.F. coupling condenser and D.C. blocking condenser. R_{11} and C_{18} act as a signal current filter in providing a return path to cathode for A.F. grid currents of the first A.F. amplifier, keeping these currents out of the C bias supply circuit and also serve to keep power pack ripple currents out of signal circuits. R_{10} provides a conductive path for the D.C. bias voltage, since it is high in ohmic value, the entire A.F. voltage fed through C_{17} by potentiometer R_8 is developed across it.

C_{19} is an R.F. by-pass condenser which shunts to ground any R.F. currents which may reach the plate of the type 75 tube. R_{12} is the load resistor for this tube, with signal current filter R_{13}-C_{20} providing a path to ground and the cathode of the 75 tube for A.F. currents after they leave the load, thereby keeping these currents out of the power pack; R_{13} and C_{20} also prevent power pack ripple currents from entering the plate circuit.

C_{21} is a D.C. blocking and A.F. coupling condenser, while R_{15} and C_{22} act as a signal current filter for the grid of the type 42 output tube. R_{14} is a grid resistor which permits application of the bias voltage to the grid.

Filament current for the four signal circuit tubes is provided by a separate winding (marked XX) on the power transformer. Since heater-type tubes are used, there is no electrical connection between filament and signal circuits, and no filter or by-pass condensers are required. The filament leads will, of course, be twisted or run close together under the chassis to lessen their magnetic effects on adjacent wires and parts. Notice the dotted line in the core of power transformer T_6; this represents an electrostatic shield made of a layer of metal foil actually placed between the primary and secondary windings to eliminate electrostatic coupling which might, under certain conditions, transfer undesirable power line disturbances to the secondary winding and the receiver circuits.

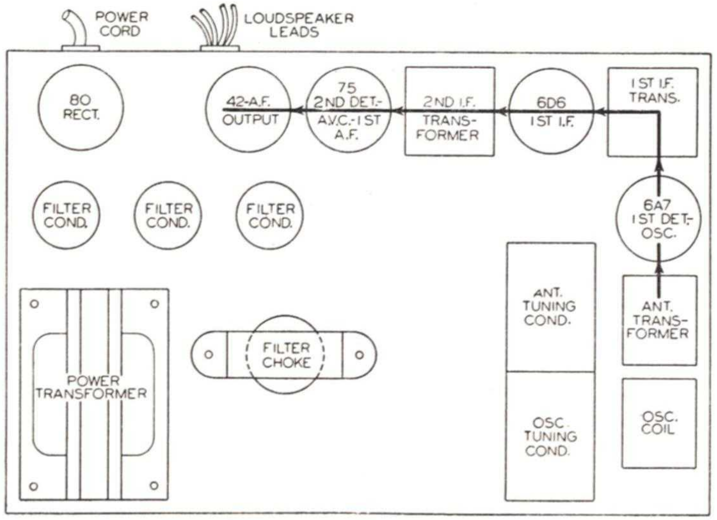

Fig. 20. Logical chassis layout (top view) for the 5-tube superheterodyne receiver circuit of Fig. *18*.

We have thus made a thorough analysis of the receiver circuit. Very seldom does a practical radio man have to study a circuit as thoroughly as this, but since he may have to analyze a particular section of the circuit in which trouble has developed, it is well for you to go over complete circuits like this occasionally during your training period.

A common and widely-used arrangement of parts for a 5-tube receiver like that just studied is given in Fig. *20*, which represents the top view of the chassis. In a receiver of this type, only the parts shown in Fig. *20* are mounted above the chassis; all the other parts are located underneath, with the chassis serving as an effective shield. Notice how parts which are connected together are placed close together; for example, the oscillator tuning condenser is alongside the oscillator coil, and the antenna transformer and tuning condenser are likewise near each other. The signal circuit tubes and transformers are arranged in the same order as on the circuit diagram, as indicated by the arrow line in Fig. *20*. In any radio receiver you will find the parts so arranged on the chassis that the path taken by signal currents from tube to tube *does not cross itself anywhere, with the end of the path* (the output circuit) *as far as possible from the starting point* (the antenna circuit); *this lessens the chances for feed-back and simplifies the shielding problem.*

Notice also that the power pack components—the power transformer, filter choke, filter condensers and the type 80 rectifier tube—are all grouped at one end of the chassis, as far as possible from the antenna input circuit, with the power cord entering the chassis just behind the rectifier tube. This lessens the chances for A.C. power line hum to get into the input circuit and be amplified by the entire receiver along with signal currents. You will find that the power transformer is completely shielded by its steel housing. As a further precaution against magnetic interaction, the filter choke is located at right angles to the power transformer.

All signal circuit coils and transformers above the chassis are in copper or aluminum shields, which prevent interference effects of stray electric and magnetic fields. Since the tubes all have glass envelopes, they are likewise covered with metal shields.

Wiring and leads for all components under the chassis of this receiver will in general be as short as possible, with all chassis connections for any one stage being made to the same point to eliminate the effects of stray signal current in the chassis. If you encounter leads in a manufactured receiver which seem unnecessarily long, do not change them unless you know definitely that they are causing trouble; oftentimes it is necessary to use long leads in order to get around certain parts and eliminate interfering effects.

TEST QUESTIONS

Be sure to number your Answer Sheet 20FR-3.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. In what three different ways can undesired signal currents enter a circuit?
2. Why is a by-pass condenser commonly placed across the C bias resistor in the cathode circuit?
3. How can signal currents be kept out of the high-resistance path through the plate supply of a radio circuit?
4. Why do signal currents take the path through a by-pass condenser in preference to other possible paths between two points in a receiver circuit?
5. Can a signal current filter act both ways, preventing signal currents from getting out of a signal circuit and preventing A.C. power supply currents from getting into the signal circuit?
6. Why should all by-pass condensers in a single R.F. stage be connected to a common point in the stage?
7. Why must grid and plate leads in an R.F. stage be kept as short and as far apart as possible?
8. Is it important to ground an electric shield?
9. Name two materials which serve best as magnetic shields at high frequencies (above about 50 kc.)?
10. Why are chassis parts so arranged that the signal current path from tube to tube does not cross itself at any point, and its end (the output tube) is as far as possible from the starting point (the antenna circuit)?

YOUR HEALTH

There is a definite relationship between a man's mental ability and his physical condition; for example, overeating is generally followed by a lazy feeling and a desire to sleep. The mind becomes less active. A headache may develop, along with a gloomy, crabby, or disgusted-with-life-in-general feeling. Certainly a man cannot do his best work when feeling this way.

Blue Mondays are quite real, and are caused by too much food and too little mental and physical exercise on Sunday, combined with a troubled sleep or too little sleep Sunday night. It takes several days for the human system to get back to normal after a week-end of excesses, so it may not be until Wednesday that you work with a clear mind. Then you find it easy to concentrate, and work becomes a pleasure.

Every day *can be like this* — if you take proper care of yourself, with physical exercise each day in the open air, and a good sound sleep each night.

Give your health the attention it deserves, and you will be rewarded many times by increased happiness and increased success in your work.

J. E. Smith